

FY16 ASME High Temperature Code Activities

Nuclear Engineering Division

About Argonne National Laboratory

Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Argonne, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

DOCUMENT AVAILABILITY

Online Access: U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via DOE's SciTech Connect (<http://www.osti.gov/scitech/>)

Reports not in digital format may be purchased by the public from the National Technical Information Service (NTIS):

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd
Alexandria, VA 22312
www.ntis.gov
Phone: (800) 553-NTIS (6847) or (703) 605-6000
Fax: (703) 605-6900
Email: **orders@ntis.gov**

Reports not in digital format are available to DOE and DOE contractors from the Office of Scientific and Technical Information (OSTI):

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
www.osti.gov
Phone: (865) 576-8401
Fax: (865) 576-5728
Email: **reports@osti.gov**

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor UChicago Argonne, LLC, nor any of their employees or officers, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of document authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, Argonne National Laboratory, or UChicago Argonne, LLC.

FY16 ASME High Temperature Code Activities

Nuclear Engineering Division
Argonne National Laboratory

September 2016

Prepared by

M.J. Swindeman, Cromtech Inc.
R.I. Jetter, R.I. Jetter Consulting
T.-L. Sham, Argonne National Laboratory

ABSTRACT

One of the objectives of the ASME high temperature Code activities is to develop and validate both improvements and the basic features of Section III, Division 5, Subsection HB, Subpart B (HBB). The overall scope of this task is to develop a computer program to be used to assess whether or not a specific component under specified loading conditions will satisfy the elevated temperature design requirements for Class A components in Section III, Division 5, Subsection HB, Subpart B (HBB). There are many features and alternative paths of varying complexity in HBB. The initial focus of this task is a basic path through the various options for a single reference material, 316H stainless steel. However, the program will be structured for eventual incorporation all the features and permitted materials of HBB. Since this task has recently been initiated, this report focuses on the description of the initial path forward and an overall description of the approach to computer program development.

Intentionally Blank

Table of Contents

Abstract.....	i
List of Figures.....	v
1 Introduction.....	1
2 Scope.....	2
2.1 Design Rules and Limits for Load-Controlled Stresses	2
2.2 Design Rules and Limits for Deformation Controlled Stress and Strain	2
3 Computer Program Features and Approach	3
3.1 Definitions	3
3.2 Object Classes in the HBB Software.....	3
3.3 Excel Interface.....	5
3.4 Flow Diagrams and HBB Software.....	5
4 Summary	8
Acknowledgement	9
Distribution list	11

Intentionally Blank

LIST OF FIGURES

Figure 1. Initial Programming Step, Linearization and Classification 6

Figure 2. Example Flow Diagram Satisfaction of Strain Limits Using Elastic Analysis (Test A-1
and A-2) 7

Intentionally Blank

1 Introduction

One of the objectives of the ASME high temperature Code activities is to develop and validate both improvements and the basic features of Section III, Division 5, Subsection HB, Subpart B (HBB). To accomplish this, it is usually necessary to provide a comparison between the proposed improvement and the reference rules in HBB. HBB is also used to assess components in comparative design studies. However, there are many features and alternative paths of varying complexity in HBB and even the most direct can be costly to evaluate. Also, because of the complexities of HBB, there can be difficulty in the correct interpretation of the requirements. For these evaluations in accordance with HBB, it would be advantageous to have the rules incorporated in a computer program to achieve economical and correct solutions. Because of the many features and alternative paths of varying complexity in HBB, the initial focus of this task is a basic path through the various options for a single reference material, 316H stainless steel. However, the program will be structured for eventual incorporation all the features and permitted materials of HBB.

2 Scope

2.1 Design Rules and Limits for Load-Controlled Stresses

HBB provides rules for both design Loadings and Level A, B, C and D Service Level Loadings. The rules cover both base material and bolting. Factors are provided to account for deterioration of materials in service and strength of weldments. The requirements for design by analysis are provided in HBB-3200. Additional, component specific rules are provided in HBB-3300, - 3400, -3500 and -3600 for vessels, pumps, valves and piping, respectively.

For this initial phase, Design Loadings and Level A, B, and C Service Level Loadings will be included but not Level D because these conditions are usually extreme, short-term conditions that do not involve time dependent creep properties. Both base materials and weldments will be considered but not bolting which is not usually part of the elevated temperature boundary. As an initial implementation, the component specific rules will not be included at this time. However, provisions for deterioration of materials in service will be included.

Material properties required for implementing the design rules, i.e. allowable stress values, are provided in Appendix HBB-I-14. Again, for this initial phase, only the properties for 316H stainless steel will be included.

2.2 Design Rules and Limits for Deformation Controlled Stress and Strain

The strain, deformation and fatigue limits are provided in Appendix HBB-T, which also includes the requirements for evaluation of instability and bucking. There are two sets of design rules in Appendix T. In one case, these rules are based on the use of inelastic analysis, which requires constitutive equations describing the materials response. In the second case, the rules are based on the use of elastic analysis with various adjustments and procedures to account for the actual inelastic response.

The procedures based on inelastic analysis will not be included in this phase nor will the buckling limits, which are not usually applicable to pressurized components. Thus, the Appendix T strain limits based on elastic analysis (HBB-T-1320) and simplified inelastic analysis (HBB-T-1330) will be included except for HBB-T-1333, which is seldom, if ever used. The evaluation of creep-fatigue limits in T-1400 will be based on elastic analysis (HBB-T-1430) and will not include the equivalent stress quantities in HBB-T-1411 for inelastic analysis. The requirements for welds in HBB-T-1710 are included.

The material properties used for evaluation of deformation controlled stress and strain, e.g. fatigue design curves and isochronous stress-strain curves are provided in HBB –T-1420-1 and HBB-T-1800 respectively. However, again, only 316H stainless steel is being included in this first phase.

3 Computer Program Features and Approach

The program framework relies heavily on two elements of modern programming: (1) the program is event driven and (2) the program is object oriented. Thus, it may be necessary to be somewhat familiar with some terminology associated with the programming techniques. In order to differentiate terms used in the ASME BPV code from similar terms used in programming, programming terms are represented in boldface. Names given to programming structures are set in italics.

Most modern codes take full advantage of object-oriented programming through class structures. Visual Basic for Applications adds the event driven aspects through the interface with Microsoft Excel. For example, a command button object may be placed on a worksheet. When the button is pressed, an event occurs and a routine is run within VBA. Event based programming can be constructed in other codes as well.

3.1 Definitions

Class: A programming structure used to group together a set of variables (**properties**) and routines (**methods**) that may call for multiple **instances** of these **classes** (collectively called **objects**) in the execution of the **program**. For example, in object-oriented finite element analysis, there may be a **class** called *element* that has properties such as *volume*, *coordinates*, *stresses*, and so forth.

Object: A particular **instance** of a **class**. In the above case, “element 47” may be a particular *element object* with its own unique set of **properties**.

Properties: the variables that characterize an **object** such as *length*, *color*. **Properties** may be other **objects**. For example, the *material property* of a finite element **object** may refer to an **object** of the *material class*.

Method: Is a subroutine associated with a particular **class**. The **method** may refer to an action done on or by a particular **object**.

Collection: is programmatic unit that consists of (or **contains**) a set of **objects**, usually of the same or consistent **class**. For example, the *elements collection* would refer to all *elements* in a finite element model.

As an example of how these various **objects** can interact. The **class** *element_set* may be defined as an **object** that has as a **property**, *name*, and a **collection**, *elements*, of *element objects*. Its **methods** may consist of commands like *delete* which empties *elements* and *sort* which orders *elements* in some manner.

3.2 Object Classes in the HBB Software

In order to understand how the HBB software is intended to work it is necessary to understand the fundamental **object classes** of the program.

Stress Classification Line (SCL). This serves as the interface between the structural analysis program and the HBB software. The *SCL* essentially holds all the information in the first two columns of Table HBB-3217-1. *Stress Classification Lines* will be composed of the following

properties.

- *LineType* (an enumeration “1” for points along a line, “2” for two-dimensional, “3” for three-dimensional, and “0” for pre-processed results).
- *Number of Points*
- *Coordinates*: coordinate locations, not used for pre-processed results
- *Vessel Component Type* (cylindrical or spherical shell, flat head, etc.)
- *Location* (remote from discontinuities, near nozzle, etc.)
- A **collection** of *Results* objects for the *SCL*
- A **collection** of *Cycles* the *SCL* is involved in
- A **collection** of *Analysis Cases* the *SCL* is involved in

Results. These objects hold the stress results in terms of raw components, linearized stresses and strains, or both for a given *SCL*. Properties include

- *Analysis Case object*
- Stress Components
- Strain Components (Appendix T calculations)
- Mean, Bending, and Peak Stress
- Temperatures (uniform or varying)

Analysis Case. Essentially this object holds the information in column 3 of table HBB-3217-1

- Case Description (Origin of Stress)
- Temperature (for isothermal case) and/or other descriptive properties

Cycle. Are used for Appendix T calculations.

- Number of *Analysis Cases* in a given *cycle*
- A **collection** of *analysis case objects*
- A **collection** of *SCLs* defined for this *cycle*

Material. The material properties consist of data from tables in mandatory appendix I-14, allowable stress intensity as a function of time and temperature. Various charts from Appendix T will also be included as properties of the material.

- Stress limits: S_0 , S_m , S_T , ...
- Yield strength from table Y-1

Analysis. The **object** that contains all the more basic **objects** associated with the analysis (*SCL*, *Results*, *Materials*, *Analysis Cases*, *Cycles*, and *Materials*) as a single unit and includes the HBB evaluations as **methods**. Only one instance of this **object class** is anticipated.

Properties of the *Analysis class* include

- A **collection** of each the fundamental **object classes**
- The HBB Evaluations as **methods**
- An array, *Evaluations*, of Boolean variables corresponding to the HBB evaluations which can be turned on and off
- The “main program” as a **method** called from the spreadsheet which branches off to the various *evaluations* to be performed.

Evaluations refers to the various procedures to determine the acceptability of a design. The **methods** in the *evaluation* range from simple (as in FIG HBB-3221-1) to complex in Appendix T. For example paragraph T-1430, “LIMITS USING ELASTIC ANALYSIS” represents an *evaluation*. Evaluations may be broken down into individual *Tests* where acceptability can be demonstrated by multiple equations (see for example HBB-T-1322, HB-T-1323, and HB-T-1324).

3.3 Excel Interface

Excel will serve as the interface for both the input and the results tabulated output and display.

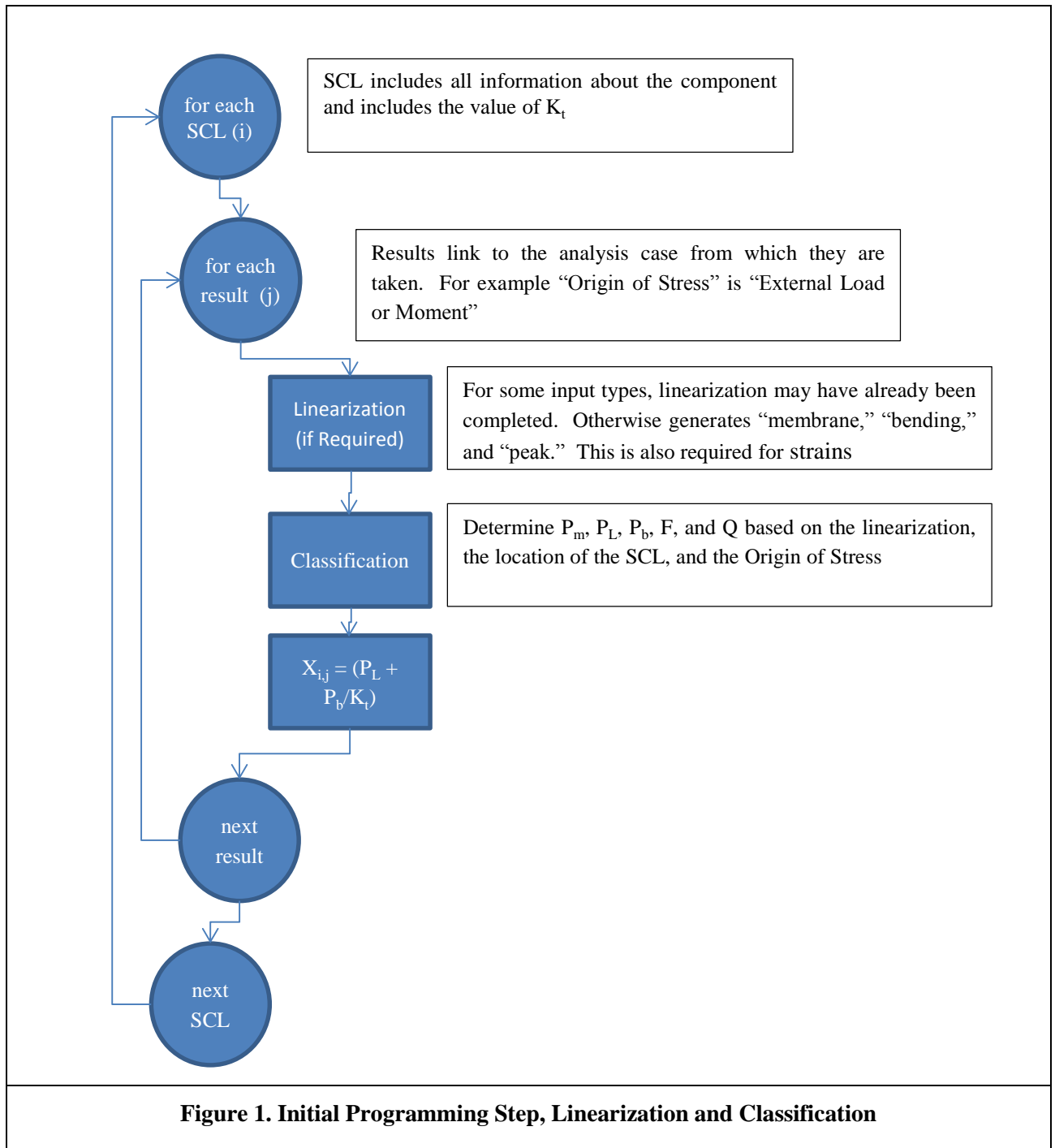
Separate worksheets will hold the information about the analysis, stress classification lines, and material data. Arrangement of information on these worksheets is still to be determined and development is incorporated in later tasks in this program. The most difficult of these input cases is the data intensive SCL. Geometry data and results data will be stored on separate sheets for compactness and readability of the critical information. A user input dialog will be used to assist with the creation and editing of the SCL.

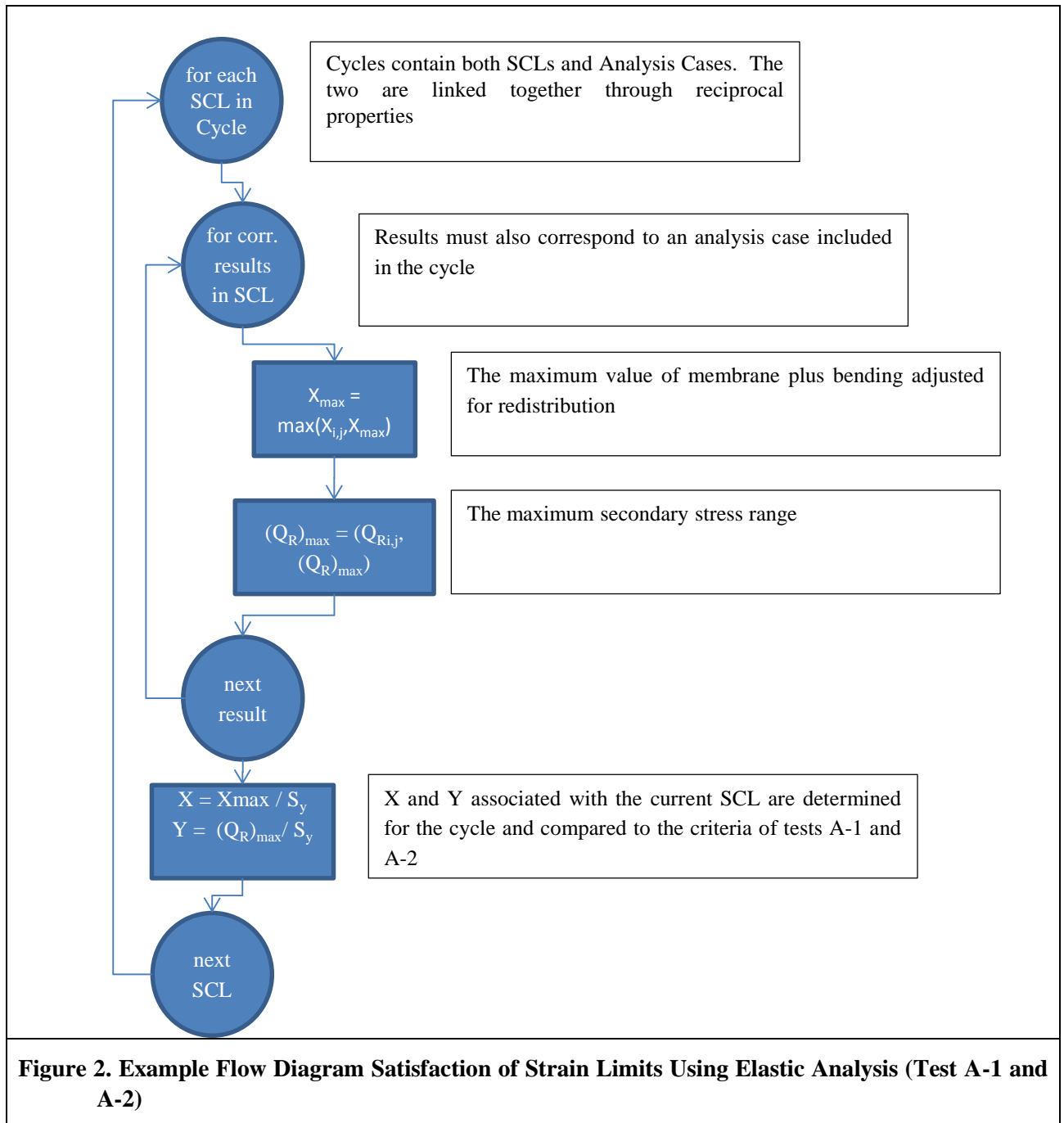
Output for each evaluation will reported on individual sheets and a summary on the main worksheet.

3.4 Flow Diagrams and HBB Software

The naming and description of the **object classes** suggests how these **object classes** relate. The flow diagrams, therefore, closely follow the analysis flow diagrams in Division 5 HBB. All of the Load-Controlled Stress Limits evaluations rely on the same initial linearization and categorization steps shown below in Figure 1 and only need to be performed once for a given analysis. Each evaluation will have a separate programmatic flow diagram and these tend to be short and simple for stress limits. Strain limit and creep-fatigue interaction evaluations involve the manipulation of cycles to determine strain ranges. More detailed flow diagrams will be developed for these cases.

An example of Satisfaction of Strain Limits (T-1322 and T-1323) is given here as shown in Figure 2. Most load-controlled stress limits are assessed by simply comparing the classified stresses with the allowable stress intensity values for the material.





4 Summary

The rules of Section III, Division 5 Subpart HBB are intended for the evaluation of the design of pressure vessels and components operating in the elevated temperature regime. In this regime time dependent inelastic effects must be accounted for. In order to avoid complex analysis with detailed material constitutive models HBB provides rules for elastic and simplified inelastic analysis methods. The current project aims to develop software to help implement these rules. The basic framework of the software relies on object-oriented programming methods and a Microsoft excel interface. The basic object classes include Stress Classification Lines, Materials, Cycles, and other classes that correspond to the methods of analysis in HBB. Flow diagrams for the different evaluations for stress limits and strain limits are currently being developed.

ACKNOWLEDGEMENT

This research was sponsored by the U.S. Department of Energy (DOE) under Contract DE-AC02-06CH11357 with the Argonne National Laboratory. Programmatic direction was provided by the Advanced Reactor Technologies (ART) Program of the Office of Nuclear Energy (NE). We gratefully acknowledge the support provided by Carl Sink Jr. of DOE-NE, ART Program Manager; William Corwin of DOE-NE, ART Materials Technology Lead; Hans Gougar of Idaho National Laboratory (INL), ART Co-National Technical Director; and Richard Wright of INL, ART Advanced Materials, High Temperature Materials, Technical Lead.

Intentionally Blank

DISTRIBUTION LIST

Name	Affiliation	Email Address
Corwin, W.	DOE-NE	william.corwin@nuclear.energy.gov
Gougar, H.	INL	hans.gougar@inl.gov
Grandy, C.	ANL	cgrandy@anl.gov
Hill, R.N.	ANL	bobhill@anl.gov
Jetter, R.I.	R.I. Jetter Consulting	bjetter@sbcglobal.net
Li, M.	ANL	mli@anl.gov
McMurtrey, M.	INL	michael.mcmurtrey@inl.gov
Nateson, K.	ANL	natesan@anl.gov
Robinson, B.	DOE-NE	brian.robinson@nuclear.energy.gov
Sham, T.-L.	ANL	ssham@anl.gov
Sink, Jr., C.	DOE-NE	carl.sink@nuclear.energy.gov
Swindeman, M.	Cromtech Inc.	cuthbert@fuse.net
Wang, Y.	ORNL	wangy3@ornl.gov
Wright, R.N.	INL	richard.wright@inl.gov
Yankeelov, J.	DOE-ID	yankeeja@id.doe.gov

Intentionally Blank



Nuclear Engineering Division

Argonne National Laboratory
9700 South Cass Avenue, Bldg. 208
Argonne, IL 60439

www.anl.gov



U.S. DEPARTMENT OF
ENERGY

Argonne National Laboratory is a U.S. Department of Energy
laboratory managed by UChicago Argonne, LLC